

# REPORT DOCUMENTATION PAGE

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14. ABSTRACT Two dilution refrigerators have been installed and made operational for the purpose of having dedicated measurement systems one at MIT and the other at the University of Rochester for carrying out quantum computing experiments. Both systems are a Kelvinox 400 model from Oxford instruments, equipped with both dc and rf lines for measurements; and both systems are vibrationally isolated and magnetically and electrically shielded for low noise measurements. Within the first year these systems have been fitted with custom-designed sample spaces and wiring. Within less than a year, this equipment has enabled the researchers to demonstrate: quantum levels in a persistent current qubit, rf and dc spectroscopy of these energy levels, and control circuits using Single Flux Quantum circuits. This equipment is enhancing our research effort to study, design, demonstrate, and develop algorithms and quantum-coherent circuitry using magnetic-flux-based superconducting qubits.					
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**Final Report for the Durint Equipment Proposal:  
Very Low Temperature Measurement System for  
Quantum Computation with Superconductors  
AFOSR Grant F49620-01-1-0351**

By

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Mark Bocko, Mark Feldman, University of Rochester;  
and M. Tinkham, Harvard University

**I. Abstract**

Two dilution refrigerators have been installed and made operational for the purpose of having dedicated measurement systems one at MIT and the other at the University of Rochester for carrying out quantum computing experiments. Both systems are a Kelvinox 400 model from Oxford instruments, equipped with both dc and rf lines for measurements; and both systems are vibrationally isolated and magnetically and electrically shielded for low noise measurements. Within the first year these systems have been fitted with custom-designed sample spaces and wiring. Within less than a year, this equipment has enabled the researchers to demonstrate: quantum levels in a persistent current qubit, rf and dc spectroscopy of these energy levels, and control circuits using Single Flux Quantum circuits. This equipment is enhancing our research effort to study, design, demonstrate, and develop algorithms and quantum-coherent circuitry using magnetic-flux-based superconducting qubits.

## **II. Experimental Equipment**

Two dilution refrigerators have been installed and made operational for the purpose of having dedicated measurement systems one at MIT and the other at the University of Rochester for carrying out quantum computing experiments. Both systems are a Kelvinox 400 model from Oxford instruments, equipped with both dc and rf lines for measurements; and both systems are vibrationally isolated and magnetically and electrically shielded for low noise measurements. Within the first year these systems have been fitted with custom-designed sample spaces and wiring. Within less than a year, this equipment has enabled the researchers to demonstrate: quantum levels in a persistent current qubit, rf and dc spectroscopy of these energy levels, and control circuits using Single Flux Quantum circuits. This equipment is enhancing our research effort to study, design, demonstrate, and develop algorithms and quantum-coherent circuitry using magnetic-flux-based superconducting qubits.

Each dilution refrigerator has the following standard features:

### **Kelvinox 400 System**

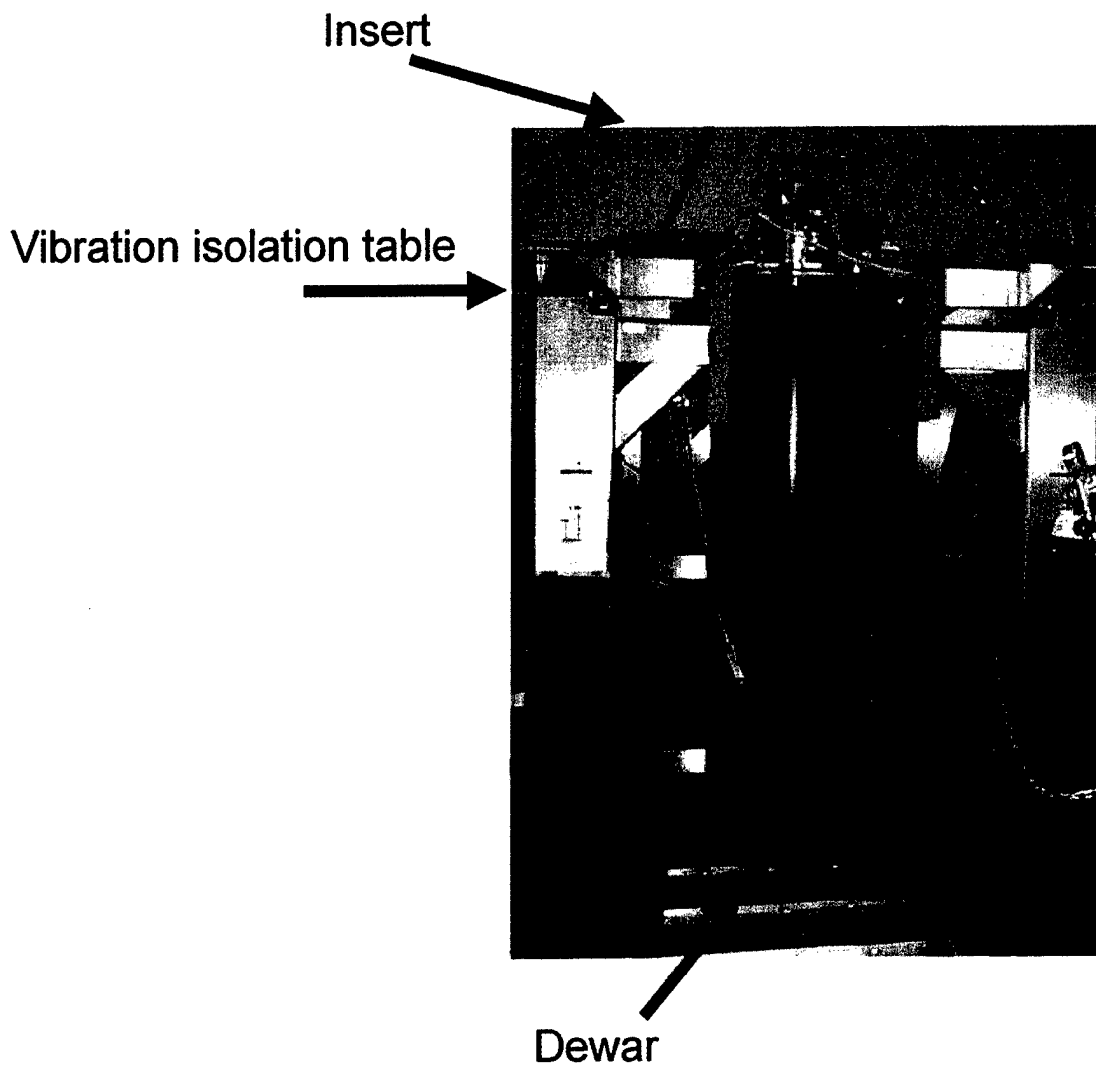
- KEL400SYS1 base system
- Vapor Shield Dewar SMD10/15VSEX
- Sliding Seal KEL400SS
- Support system MSSSMD
- HCT helium cooled trap
- Transfer tube TTN2F
- Helium mixture HE3400
- Calibrated temperature sensor
- 2 x's 24-way connector, with copper wires
- Flexible co-axis cables
- Helium level detector
- Sample holder LECSH

The two systems were purchased from  
Oxford Instruments America, Inc  
130A Baker Ave.  
Concord, MA 01742  
Tel: 978-369-9933  
FAX: 978-369-6616  
Email: [info@ma.oxinst.com](mailto:info@ma.oxinst.com)  
[www.oxford-instruments.com](http://www.oxford-instruments.com)

## II.1. The MIT System

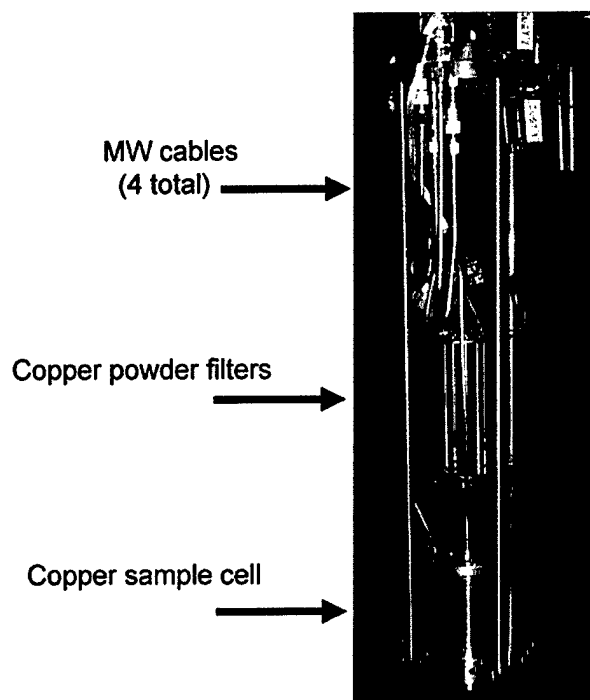
The MIT system is suspended on a vibrational table which was custom-made by  
Integrated Dynamics Engineering, Inc  
377 University Ave.  
Westwood, MA 02090  
Tel: 781-326-5700  
Fax: 781-326-3004  
email:mike.fraumeni@ideworld.com  
www.ideworld.com

The dilution refrigerator supported by its vibrational table is shown below:



*Figure 1. Vibrational table holding the Dilution Refrigerator*

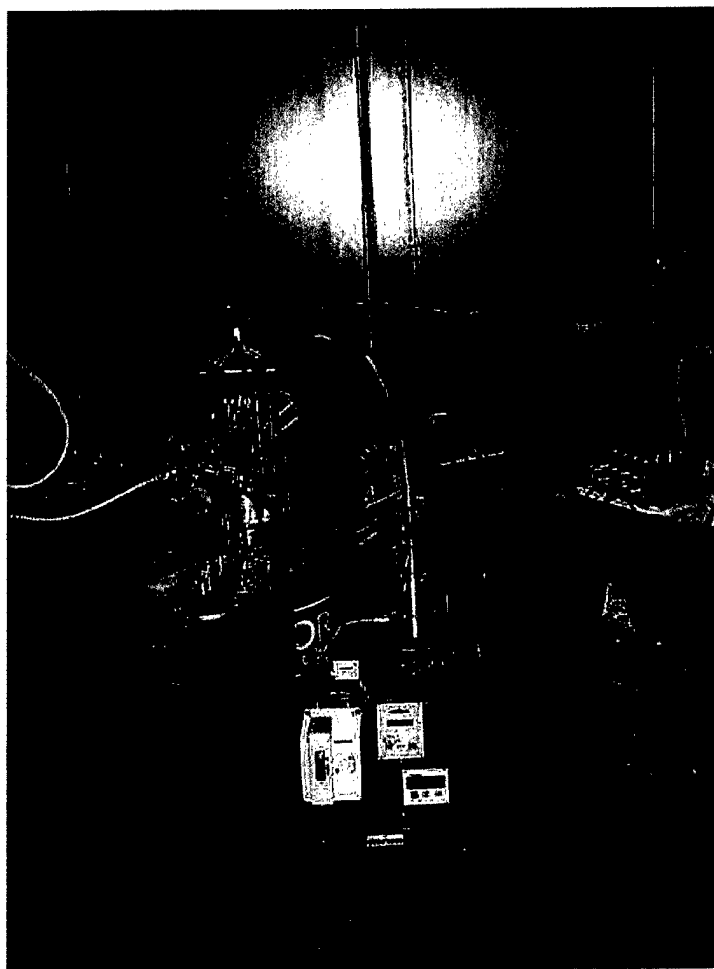
Additionally each of the 24 dc lines were specially filtered with homemade cooper powder filters which were installed to operate at cryogenic temperatures. A sample space was specially designed to minimize electromagnetic noise; especially because it was decided in the MIT system not to enclose the dilution refrigerator in a screened room. A triple layer permalloy magnetic shields were installed to operate in the liquid helium environment.



The Dilution refrigerator part of the Kelvinox 400, showing the custom-made parts: the microwave cables, copper powder filters, and the sample cell.

## II.2 The University of Rochester System

The University of Rochester system is enclosed in a shielded room, provided by Lindgren Inc., and is supported on a home-built vibration isolation platform employing Newport Inc. pneumatic isolators. The dewar extends into a 4' deep pit in the floor of the shielded room (also shielded) and the height of the room allows for easy removal and access to the probe. The system is shown below in Figure 3.



*Figure 3. University of Rochester dilution refrigerator system.*

The Rochester unit was purchased with 48 low frequency lines and 2 wide-band coax lines installed by the Oxford factory. Copper powder filters of a standard design have been installed on a subset (6) of the low frequency lines and a flip-chip mounting fixture has been installed mounted to the mixing chamber in the refrigerator. A triple layer mu-metal shield that will be mounted in the inner vacuum chamber of the unit has been designed and will be installed shortly, upon its receipt.

A base temperature of 9.5 mK was demonstrated in the commissioning of the unit and operation of RSFQ circuits at temperatures of approximately 20 mK has been achieved subsequently. The system has proven to be reliable and straightforward to use.